

YOUR NAME:

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YOUR PARTNER'S NAME:

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Pre-Lab Score: ___/35

In-Lab Score: ___/65

Total: ___/100

Wheatstone Bridge

LAB 3: Instrumentation Amplifier

ELECTRICAL ENGINEERING 43/100

INTRODUCTION TO DIGITAL ELECTRONICS

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Lab Objectives

In the previous lab, we learned about operational amplifiers and how to implement basic configurations such as the inverting and noninverting amplifiers, Schmitt trigger, and comparator. Now that you are familiar with them, we will build a sensor interface, one of the most common applications of op amps.

In this lab you will also be introduced to the strain gauge, which is a variable resistor that increases or decreases in resistance based on the physical stress applied to it. The strain gauge you will use is attached to a metal bar, so you can put weights on the bar to bend it. This will cause the strain gauge to stretch, changing the dimensions of the variable resistor and its resistance. To measure this change in resistance, you will use a Wheatstone bridge configuration in conjunction with an instrumentation amplifier.

Pre-Lab

Strain Gauges

A strain gauge operates on the principles that physical strain deforms the physical dimensions of a material. We know from physics that resistance is proportional to the length of the material and inversely proportional to the width, given by the following equation:

$$R = \frac{\rho l}{A} \text{ where } A = wh$$

When we deform the strain gauge resistor, we either increase the length l and decrease the area A , thus increasing resistance, or we decrease the length and increase the area A , decreasing resistance. Therefore the strain gauge is a **variable resistor**, represented as a resistor with an arrow through it as shown below. For the purposes of our calculations, we will neglect changes in cross-sectional area since it is very small.



Variable Resistor Circuit Symbol¹

The Wheatstone Bridge

To convert the change in resistance of the strain gauge into a voltage output, we use a Wheatstone bridge. Three resistors in this circuit have the same resistance as the nominal (unstrained) value of the strain gauge, so the output will be approximately proportional to the change in resistance ΔR arising from the fourth one.

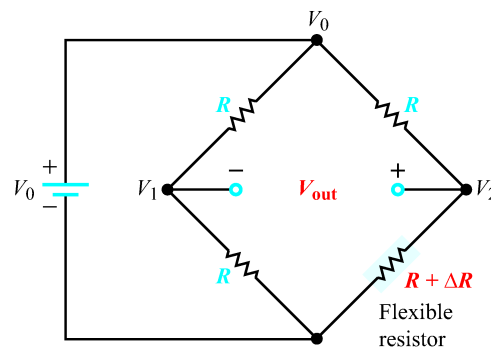


Fig. 2-32: Circuit for Wheatstone-bridge sensor¹

For the above diagram of the Wheatstone bridge, show that the following relationship in an ideal case is true:

$$V_{out} \cong \frac{V_0}{4} \left(\frac{\Delta R}{R} \right)$$

Score: __/10

Unfortunately, in practicality it is almost impossible to construct a perfect Wheatstone bridge. The main problem is resistor tolerance, as was discussed in the resistors lab. Recall that resistor tolerance falls in the range of $\pm 5\%$ and the voltage difference we want to measure is given by two voltage dividers. On the other hand, the relative change in resistance that we want to observe is very small, on the order of 0.1%.

This means that if we arbitrarily choose some 5% resistors, we will already have some difference V_{offset} before we apply strain to obtain the voltage change dV from the strain gauge. Clearly $V_{offset} \gg dV$, so we need to somehow eliminate V_{offset} ; otherwise, after we apply the gain G to the difference, we will get $G(V_{offset} + dV)$, when we really want $G(dV)$.

To solve this problem, you are going to have to add or subtract voltage from one of the nodes in the Wheatstone bridge. This can be done with the 6V power supply. The output will then be connected to the instrumentation amplifier.

The Instrumentation Amplifier

To summarize, the bridge circuit gives us a way to measure the resistance change of the strain gauge. One of the problems with using strain gauges is that the changes in resistance are on the order of 10^{-5} , so they are very difficult to detect. The solution to this problem is to use a high gain operational amplifier to detect changes in the voltage levels, rather than changes in resistance.

Below is the implementation of the instrumentation amplifier. Using the assumptions for ideal operational amplifiers, derive the following relationship between the input voltages and the output voltage:

$$v_o = \left(\frac{R_1 + R_2 + R_3}{R_2} \right) \left(\frac{R_4}{R_5} \right) (v_2 - v_1)$$

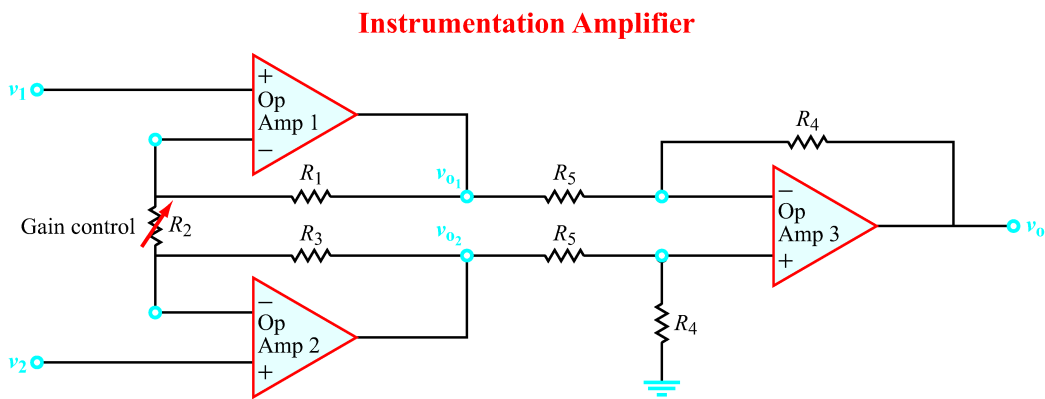


Figure 4-20: Instrumentation amplifier circuit.¹

Score __/25

¹ Ulaby and Maharbiz, Circuits. Figure 4-20

(More Space)

Lab Section

The Instrumentation Amplifier

Recall that the purpose of the Wheatstone bridge is to determine small differences in resistance through voltage measurements. Build the bridge circuit using a strain gauge as the variable resistor. Choose your other three resistances such that your circuit works approximately as you analyzed it in the pre-lab. You will need to first measure the resistance of the strain gauge without any added weight.

Strain Gauge Resistance: _____

Resistance Value of Three Other Resistors: _____

Score: ___ / 5

Ideally, without added weight on the strain gauge, the output of the Wheatstone bridge will be 0 V. Due to resistance tolerance this won't necessarily be true. Apply a DC offset to zero out the output voltage before applying weights to the strain gauge and measuring the change in voltage. Try to figure out a way, just using a separate power supply, that you can add voltage to change the output to zero.

Next, build the instrumentation amplifier. Determine suitable resistances such that your circuit will work as desired. The voltage you want to amplify is the output of the Wheatstone bridge, so you will want to connect that as the input to the instrumentation amplifier.

The final circuit to build is the instrumentation amplifier in Fig. 4-20 above. The inputs v_1 and v_2 correspond to the output terminals of the Wheatstone bridge. This circuit, which in itself requires three op amps, will be sufficiently complicated that debugging may get very difficult. Therefore, it is of the utmost importance that you **test and verify** each step along the way, so that there are no surprise failures at the end.

Separate the circuit into small, testable sub-circuits. Test the Wheatstone bridge separately from the instrumentation amplifier can be tested. Make sure both work independently before connecting them together. The amplifier can be broken down further, as you can test the buffer stage of two op amps independently from the final amplification op amp. Patiently testing each sub-circuit along the way can save a lot of headaches and time at the end.

In the space provided below, state what resistances you chose to use for the instrumentation amplifier and why you chose those values. Also, compute the theoretical gain of the instrumentation amplifier that you built using your resistor values.

Score __/10


Now take the appropriate measurements to determine the change in resistance of your strain gauge caused by the addition of a 200g weight at the end of the gauge. Explain all necessary measurements and calculations in the space provided below or on a separate sheet of paper. Note that you may need to measure the **actual** gain of your amplifier, which may be different from the theoretical gain previously calculated. Include this measurement and explain the discrepancy, if it exists.

Score __/20

(More space)

Show your final circuit to your lab GSI for check off and demonstrate a reasonable change in voltage when you apply weights to the strain gauge. Your initial configuration should output as close to zero as possible.

Your GSI Signs Here **(30 pts)**



Why do we care?

Instrumentation amplifiers are designed to have extremely high gain and are usually preferred over stand-alone amplifiers, due to noise and interference considerations.

In many real-life situations, you may be dealing with extremely low level microvolt signals. In order to achieve the necessary gains to detect that kind of signal, you will have to use a high gain instrumentation amplifier in order to process the signal.

If you wish to use one for the final project, you will be building the instrumentation amplifier using discrete components as you did for this lab. It would be a good idea to take a look at your working implementation and understand how it works.

Lab Report Submissions

This lab is **due at the beginning** of the following lab section. Make sure you have **completed all questions** and **drawn all the diagrams** for this lab. In addition, attach any loose papers specified by the lab and submit them with this document.

These labs are designed to be completed in **groups of two**. Only one person in your team is required to submit the lab report. Make sure the names and student IDs of **BOTH** team members are on this document (preferably on the front).

Image Citations

Textbook Images are courtesy of Fawwaz T. Ulaby and Michel M. Maharbiz and National Technology and Science Press.

Fawwaz T. Ulaby and Michel M. Maharbiz, Circuits © 2009 National Technology and Science Press

ⁱ <http://www.c1ker.com/clipart-24578.html>